REMARKS/ARGUMENT

Regarding the Claims in General:

Claims 19-70 are now pending. Claim 18 has been replaced by claim 40, and claims 20-21, 26, 28, 31-35, and 37-39 have been further amended to clarify certain recitations in the claims as previously presented, to eliminate some possible ambiguities, and to further improve the form of the claims for purposes of examination under U.S. practice. The claims have not been narrowed by these changes.

Claims 41-70 have been added to provide applicants with additional protection to which they appear to be entitled in light of the prior art.

Regarding The Allowable Subject Matter

Applicants note with appreciation the indication that claims 22-25, and 33-36 would be allowed if rewritten in independent form incorporating the limitations of their respective parent claims. Because these claims are all now ultimately dependent on claim 40, which is believed to be allowable as explained below, claims 22-25, and 33-36 have been retained in dependent form pending the Examiner's further consideration. The amendments herein to claims 33-35 do not affect the patentability thereof.

Regarding the Prior Art Rejections:

It remains applicant's position that claims 19-40 are patentable over the Izawa et al., Hervig, Winfield et al., Hsu et al. and Weinberger et al. patents for the reasons stated in the March 18, 2004 response to the December 18, 2003 Office Action, the entirety of the Argument section therein being incorporated herein by reference as if fully set forth. The Examiner is respectfully referred to those arguments for the details of applicants' position. Claim 41, which is dependent on claim 40, specifies the presence of a plurality of pairs of sealing blocks. With respect to new claim 42, this represents specific selection criteria for the flow pipe and the carrier pipe which were previously in claim 18. Claim 40 has been broadened by extracting these limitations for presentation in claim 42.

As to claims 43-70, these are apparatus claims patterned after claims 19-42, and are patentable for the same reasons.

Finally, as background information which may be helpful to the Examiner, there is submitted herewith *Buckle Arrestors for Deepwater Pipelines* by Carl G. Langer, presented at the Offshore Technology Conference in Houston, Texas, May 3-6, 1999. Applicants do not consider this document as material to patentability, but submit it to provide the Examiner with a perspective on the complex problems facing those who practice in this art, and to demonstrate the dramatic differences between the issues in this art, and those in the arts to which the references cited by the Examiner pertain.

In view of the foregoing, favorable reconsideration and allowance of this application are respectfully solicited.

I hereby certify that this correspondence is being transmitted via facsimile to (703) 872-9306, addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date indicated below:

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Name of applicant, assignee or Registered Representative

Lawrence A Hoffman
Signature

May 19, 2004
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dt Rejected BA.

OTC 10711

Buckle Arrestors for Deepwater Pipelines

Carl G. Langner / Langner & Associates

This paper was prepared for presentation at the 1999 Offshore Technology Conference held in Houston, Texas, 3–6 May 1999.

Abstract

Progress has been made in the design of buckle arrestors, or more precisely collapse arrestors, for deepwater pipelines. Empirical relationships have been developed for the design of both integral ring and grouted sleeve arrestors, forming the basis of a simple and straightforward design procedure. The good agreement between the latest design formulas and the crossover pressure data obtained from large scale tests by Shell E&P Technology Company and by Professor Kyriakides at U.T. Austin over the past few years, should result in more efficient and reliable buckle arrestors for deepwater pipelines.

Introduction

An offshore pipeline which has been damaged locally may fail progressively over long distances by a propagating collapse failure driven by the hydrostatic pressure of the seawater. The pressure required to propel a propagating collapse is much smaller than the pressure required to initiate collapse of an undamaged pipe. For deepwater pipelines it is often uneconomical to design the pipeline with sufficient strength to prevent a propagating collapse failure. Such pipelines are designed to prevent buckling and collapse failures due to normal combined bending and external pressure loads, but are left vulnerable to propagating collapse failures initiated under extraordinary circumstances.

In such cases, it is feasible to install buckle arrestors, such as thick-wall rings, at intervals along the pipeline. A series of such arrestors, each sufficiently strong to stop a propagating collapse failure, will limit the extent of damaged pipe in event of a mishap. In general, the distance between buckle arrestors is selected to enable repair of the flattened section of pipeline between two adjacent arrestors, at "reasonable" cost. For pipelines installed by J-Lay, the buckle arrestors also serve as pipe support collars. In this case the distance between arrestors is simply the length of each J-Lay joint.

Three types of buckle arrestors are in common use, namely Grouted Sleeve arrestors, Integral Ring arrestors, and Thick Wall Pipe Joints. Grouted Sleeve arrestors are steel sleeves that are slid over the ends of selected pipe joints and are grouted in place, as shown in Figure 1, before being installed offshore. Grouted Sleeve arrestors are preferred, where feasible, because of their low cost. However, this type of arrestor has limited usefulness in deep water because, as external pressure increases, a collapsed pipe will transform from its normal flat "dogbone" cross section into a C-shaped cross section which then passes through the arrestor. Hence, for sufficiently deep water, even an infinitely rigid Grouted Sleeve arrestor is ineffective.

Integral Ring arrestors are thick-wall rings that are welded into selected pipe joints, as illustrated in Figure 2, before being installed offshore. Integral Ring arrestors are used for pipelines in which the strength of sleeve type arrestors is not adequate, and for J-Lay applications that require a support collar on each pipe joint. These arrestors are very efficient in terms of strength for a given amount of steel, but are more expensive than sleeve arrestors because of the additional welding required. Thick Wall Pipe Joint arrestors are special pipe sections, each designed to prevent collapse propagation, that are welded into a pipeline at intervals. A Thick Wall Pipe Joint is essentially a very long integral ring arrestor, but is much less efficient in the amount of steel used.

Early studies of propagating buckles and buckle arrestors, Refs. 1 through 3, provided general guidance for the design and utilization of buckle arrestors on offshore pipelines. The many subsequent publications by Kyriakides and his colleagues, Refs. 4 through 14, expanded and refined our understanding of the various phenomena involved in initiation, propagation, and arrest of collapse failures in pipelines and other structures. This paper presents new design formulas for "narrow" integral ring arrestors which correlate well with the existing data. Such arrestors are particularly useful for deep-water pipelines because of their high strength buckle arresting capabilities. Also presented are alternative design relationships for "wide" integral arrestors and for

grouted sleeve arrestors, which have comparable accuracy to other existing formu-lations, such as Refs. 4 and 14.

Because of the complexity of the buckle crossover phenomenon, buckle arrestor design relationships are empirical. Two distinct sets of test data exist for design of Integral Ring arrestors: one set obtained from five full-scale tests of 12" and 18" pipes/arrestors conducted in 1989, 1994, and 1996; and the other set obtained from 35 tests of 4.5" OD pipes/arrestors conducted in 1982 and 1996. These data are listed in Tables 1 through 3. The two sets of data differ in the length-to-thickness ratios of the arrestors, being L/h = 0.9 – 1.8 for the full-scale tests and L/h = 4.6 – 21 for the smaller pipe tests. They also differ in arrestor efficiencies as will be explained in the data comparisons section below. In addition to the data for integral ring arrestors, this paper presents 17 new test data for Grouted Sleeve arrestors obtained from 6" and 16" pipes in 1996. These data are listed in Table 4.

Arrestor Design Formulas

The following pipe properties must be computed for each pipeline section before performing buckle arrestor design calculations.

Collapse pressure

$$P_c = P_y P_e / (P_y^2 + P_e^2)^{1/2} \quad \ldots\ldots (1)$$

$$P_y = 2Y\, t/D \quad \text{and} \quad P_e = 2.2E(t/D)^3$$

Propagation pressure

$$P_p = 24\, Y\, (t/D)^{2.4} \quad \ldots\ldots (2)$$

Minimum crossover pressure

$$P_m = 1.35\, \gamma H_{max} \quad \ldots\ldots (3)$$

Minimum arrestor depth

$$H_a = P_p / 1.25\, \gamma \quad \ldots\ldots (4)$$

In these formulas, D is pipe outside diameter, t is pipe wall thickness, Y is yield stress (SMYS), E is elastic modulus, γ is the density of seawater, and H_{max} is the maximum water depth associated with a given section of pipeline. The collapse pressure P_c is a lower bound prediction of the net external pressure required to initiate a collapse failure in a nominally round pipe. The propagation pressure P_p is the minimum external pressure that will cause a collapse failure to propagate along a pipeline. Eqns. (1) and (2) are well established in the literature as appropriate for collapse design of pipelines (Refs. 15, 16); however, other equivalent formulas may be used if preferred.

The strength of any buckle arrestor is expressed by its crossover pressure P_x, which is the minimum external pressure that can force a collapsed section of pipe to "cross over" the arrestor and begin collapsing the undamaged pipe on the other side. The minimum crossover pressure for a "weak" arrestor is simply the propagation pressure P_p and the maximum crossover pressure for a "strong" arrestor is simply the collapse pressure P_c of the pipe. A useful parameter that varies between 0 and 1, depending on the arrestor strength, is the arrestor efficiency η, defined by

$$\eta = (P_x - P_p)/(P_c - P_p) \quad \ldots\ldots (5)$$

The design crossover pressure (as calculated below) must equal or exceed the minimum crossover pressure P_m, thus providing a minimum safety factor of 1.35 for any buckle arrestor. Buckle arrestors must be employed along a pipeline at all depths greater than the minimum arrestor depth H_a. At depths less than H_a a pipeline is in no danger of collapse propagation. Note that values of P_c, P_p, P_m, and H_a must be computed for every section of a pipeline that has different pipe specifications.

Thick Wall Pipe Joint. Thick Wall Pipe Joints have been used as buckle arrestors in situations where suitable thick-wall joints are readily available and where the weight of the suspended pipeline during laying is not a critical issue. The design of a thick wall pipe joint arrestor is obtained by equating the minimum crossover pressure P_m (Eqn. 3) with the design crossover pressure P_x which is the same as the propagation pressure P_p (Eqn. 2), and solving for the thickness of the Thick Wall Pipe Joint. Thus

$$t/D = [P_m / 24\, Y]^{0.4167} \quad \ldots\ldots (6)$$

Integral Ring Arrestors. Integral Ring arrestors are forged and/or machined weld-neck rings that are butt-welded into a pipe joint that has been cut into two pieces, as shown in Fig. 2. A less expensive version of an integral ring arrestor slides over the pipe and is fillet-welded both sides onto the outside of the pipe joint. Special restrictions may have to be placed on the utilization of this type of arrestor because of stress concentrations, etc. As mentioned previously, integral arrestors are required for applications in which the strength of sleeve-type arrestors is not adequate, and for J-Lay applications that require a support collar on each pipe joint.

Integral Ring arrestors may be categorized as either "narrow" or "wide". Narrow arrestors, in which the length-to-thickness ratio varies between L/h = 0.5 – 2.0, are used primarily for pipelines installed by J-Lay; here the arrestor doubles as a collar for supporting the suspended pipe span. Wide integral arrestors, where L/h > 2, are used primarily for pipelines installed by S-Lay, because of the easier passage of this type of arrestor through the tensioners and over the stinger rollers. Two different values of the factor k are used in the following design formulation depending on whether the arrestor is narrow or wide. The recommended design formulas for

Integral Ring arrestors are as follows, assuming that the design crossover pressure P_x is everywhere equal to or greater than the minimum crossover pressure P_m (Eqn. 3).

$$\eta \geq \begin{cases} \lambda/k, & 0 < \lambda < k \\ 1, & \lambda > k \end{cases} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

$$\text{where} \quad k = \begin{cases} 5 & \text{for } 0.5 < L/h < 2 \text{ (narrow)} \\ 8 & \text{for } L/h > 2 \text{ (wide)} \end{cases} \quad \ldots\ldots\ldots\ldots (8)$$

$$\text{and} \quad \lambda = L\,P_a / D\,P_p \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$P_a = 24\,Y_a (h/D)^{2.4} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Here η is the arrestor efficiency factor, as defined by Eqn. (5), and λ is the arrestor strength factor, which depends on the arrestor length L, thickness h, yield strength Y_a, and characteristic pressure P_a. The design factor $k = 5$ is recommended for a narrow arrestor and $k = 8$ is recommended for a wide arrestor, as indicated. Under the condition that $0 < \lambda < k$, Eqns. (7)-(9) can be solved explicitly for the arrestor length L in terms of given values of h, Y_a, D, etc. Thus

$$\frac{L}{D} \geq \frac{k\,P_p}{P_a} \left(\frac{P_x - P_p}{P_c - P_p} \right) \quad \ldots\ldots\ldots\ldots\ldots (11)$$

For $\lambda \geq k$, the design relationship reduces to $P_x \geq P_c$. Here the arrestor is sufficiently strong that the external pressure must equal or exceed the collapse pressure of the pipeline before a buckle can cross the arrestor.

Grouted Sleeve Arrestor. Grouted Sleeve arrestors are forged or fabricated steel cylinders, typically with dimensions of $L/D = 0.5 - 2.0$, that are slid over the end of a pipe joint, and grouted in place near the middle of the joint. See Fig. 1. The gap between pipe OD and sleeve ID should be as small as possible to achieve maximum arrestor strength. An annular gap of 1-2 percent of the pipe diameter is recommended. Typical grout materials that have been used are portland cement, sand-filled epoxy, and two-part polyurethane. Sleeve arrestors generally are the lowest cost type of buckle arrestor, but may not be suitable in deep water due to their limited arrestor strength. As mentioned previously, at the crossover limit, the cross section of a buckled pipeline can change from the "dog-bone" shape typical of free buckle propagation, to a "C" shape that enables the collapse wave to pass through a sleeve-type arrestor.

Two types of sleeve arrestors have been used, those that are fairly rigid and remain essentially undeformed, and those that deform significantly during a crossover event. Only the former are considered in this paper, since the current focus is on deepwater pipelines. Design formulations pertaining to deformable sleeve-type arrestors are given in Refs. 3 and 4. The recommended design formulas for Grouted Sleeve arrestors are as follows, assuming that the design crossover pressure P_x is everywhere equal to or greater than the minimum crossover pressure P_m (Eqn. 3). The strength factors

$$\lambda \geq 3, \quad L/D \geq 0.5 \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

$$\text{imply} \quad P_x \geq \min(P_1, P_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$\text{where} \quad P_1 = 2.4\,P_p, \quad P_2 = P_p + (P_c - P_p)/3 \quad \ldots\ldots\ldots (14)$$

The restriction on the strength factor ($\lambda \geq 3$) generally can be met by choosing the arrestor thickness to be at least two times the pipe wall thickness ($h/t \geq 2$), although a thinner arrestor is possible if the arrestor length is greater than the pipe diameter. Note that the predicted crossover pressure P_x is the minimum of two different formulas, P_1 and P_2. Both formulas are presented here, as it is not clear from the comparisons with existing data which of these more accurately predicts the crossover pressure of a Grouted Sleeve arrestor. The outside diameter (OD) of the arrestor is given by

$$D_a = D + 2h + g, \quad g = \text{grouted gap} \quad \ldots\ldots\ldots\ldots (15)$$

Comparison with Test Data

Figure 3 compares the Integral Ring arrestor design formula (Eqns. 7,8) with the five full-scale buckle arrestor test data obtained by Shell E&P Technology Company in tests conducted in 1989, 1994, and 1996. The data are listed in Table 1. These 12" and 18" pipe samples all utilized "narrow" arrestors, with $L/h = 0.9 - 1.8$, and all arrestors were configured to serve as J-Lay support collars. Hence the formula with "narrow" design factor, $k = 5$, was plotted together with the data in Figure 3. Note that the design curve consists of a linear portion relating the arrestor efficiency η and strength factor λ, followed by a horizontal line $\eta = 1$, where the latter represents an infinitely rigid buckle arrestor.

Figure 3 shows that the test data are well correlated with the linear portion of the design curve, having at most about 10 percent deviation. The dashed lines in Figure 3 show the anticipated range of data if additional testing were done, and help to emphasize the narrow spread in these data. Except for pure collapse tests of pipes without buckle arrestors, no data have been obtained to date to correlate with the horizontal portion of the design curve.

Figure 4 compares the Integral Ring arrestor design formula with the entire set of available test data, including the 18 test data obtained by Shell in 1982, the 17 test data obtained by Kyriakides in 1995, and the five full-scale test data referred to above. These data are listed in Tables 1-3. All 35 of the 4.5" OD test samples utilized "wide" arrestors, with $L/h = 4.6 - 21$. To highlight the differences between these

data sets, design curves for both the "wide" design factor k = 8 and the "narrow" design factor k = 5, are plotted in Figure 4. The k = 8 design curve provides a reasonable lower bound to the entire data set, and therefore is recommended as a conservative design formula for Integral Ring arrestors in general. The k = 5 design curve obviously applies only to "narrow" arrestors and would be unconservative if used to design a "wide" arrestor. A major conclusion from Figure 4 is that "narrow" arrestors are much more efficient in terms of arresting capability than "wide" arrestors, and therefore will be preferred for many deepwater pipeline applications.

Figures 5 and 6 compare the Grouted Sleeve arrestor design formulae P_1 and P_2 with the 1996 test data listed in Table 4. In these tests the 6" and 16" pipe samples were fitted with sleeve arrestors in which L/D varied between 0.45 and 1.06, and h/t varied between 1.32 and 2.55. Figure 5 plots these data as arrestor efficiency η versus the strength factor λ, as before. For the recommended strength range $\lambda \geq 3$ applicable to deep water, the design formula P_2 reduces to $\eta \geq 1/3$, which is seen to be conservative (except for one point) relative to the test data. Note that the arrestor efficiency η for Grouted Sleeve arrestors never exceeds 0.50. This contrasts with Integral Ring arrestors where η can exceed 1.0.

Figure 6 plots the Grouted Sleeve arrestor data as crossover pressure ratio P_x/P_p versus the strength factor λ. For the recommended strength range $\lambda \geq 3$, the design formula P_1 reduces to $P_x/P_p \geq 2.4$, which is seen to be conservative with respect to the test data. Because both the P_1 and P_2 formulae are conservative, the design formulae (Eqns. 12-14) are justified. It is interesting to note that the maximum crossover pressure ratio P_x/P_p for very rigid sleeve arrestors, is just over 3. Another interesting observation, from both Fig. 5 and Fig. 6, is that there is no increase in the crossover pressure for arrestors with strength factors beyond about 5. This suggests that, for economy, a design range of $\lambda = 3 - 5$ may be optimum for Grouted Sleeve arrestors to be used in relatively deep water.

Design Procedure. Following suggestions in Ref. 14, we recommend the following procedure for the design of buckle arrestors for deepwater pipelines. It is assumed that the pipeline design has been determined for one or more sections in which the diameter, wall thickness, and yield strength are specified. For each such pipeline section:

1. Calculate the collapse and propagation pressures of the pipeline, as well as the minimum crossover pressure P_m and the minimum arrestor depth H_a. If the maximum pipeline depth is less than H_a then no buckle arrestors are required. Otherwise arrestors are required over that portion of the line with depths greater than H_a.
2. Select the type of arrestor and a steel grade of the arrestor. Design equations are given for Grouted Sleeve arrestors, narrow Integral Ring arrestors, wide Integral Ring arrestors, and Thick Wall Pipe Joint arrestors.
3. Calculate an arrestor thickness and length such that the design crossover pressure Px is equal or greater than P_m. Under some situations a Grouted Sleeve arrestor will not yield a design. In this case re-design the arrestor as an Integral Ring or Thick Wall Joint arrestor. In some cases a combination of Sleeve arrestors at the shallow end and Integral Ring arrestors at the deep end are feasible.
4. To minimize risk, particularly in critical applications, it is recommended to perform a full-scale test of the proposed pipe and arrestor, utilizing accepted testing procedures.

Conclusions

1. Buckle arrestor designs exist that can protect subsea pipelines against propagating collapse failures. For shallow and moderate depths the low cost Grouted Sleeve arrestors are usually adequate. The more expensive Integral Ring and Thick Wall Joint arrestors are capable of containing pipeline collapse failures in any water depth, provided the external pressure does not exceed the collapse pressure of the pipe.
2. Design formulas together with a design procedure have been developed for each of the various types of buckle arrestors. Comparisons with test data show that these design formulas are both efficient and reliable.
3. The most efficient buckle arrestors are "narrow" Integral Ring arrestors with thickness and length of similar size. Because of its strength, this type of arrestor will be preferred for many deepwater pipeline applications.

Nomenclature

D = outside diameter of the pipeline, in
D_a = outside diameter of a Grouted Sleeve arrestor, in
E = Young's elastic modulus, psi
h = thickness of buckle arrestor, in
H_a = minimum arrestor depth, ft
H_{max} = maximum water depth along pipeline section, ft
k = design factor for Integral Ring arrestor
L = length of buckle arrestor, in
P_a = arrestor characteristic pressure, psi
P_c = collapse pressure of the pipeline, psi
P_e = elastic buckling pressure of pipeline, psi
P_m = minimum crossover pressure, psi
P_p = propagation pressure of the pipeline, psi
P_x = crossover pressure of pipe/arrestor combination, psi
P_y = yield pressure of the pipeline, psi
P_1, P_2 = crossover pressure formulas for sleeve arrestor, psi
t = wall thickness of the pipeline, in
Y = yield strength (SMYS) of the pipeline, psi
Y_a = yield strength of the buckle arrestor, psi
γ = weight density of seawater, psi/ft
η = arrestor efficiency factor, varies between 0 and 1
λ = arrestor strength factor

Acknowledgments

This work relies wholly on the significant quantity of high quality, large scale collapse test data involving pipes and arrestors provided by Shell E&P Technology Company and Stelios Kyriakides over the past several years.

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TABLE 1. FULL SCALE INTEGRAL RING BUCKLE ARRESTOR DATA

Data from Shell Integral Arrestor Tests of 12" and 18" Pipe

	PIpe Data					Arrestor Data					Observ Crosso Press	Arre Stren Fac	Arrestor Efficiency
Tes Dat	D	t(	Y(k	Pc(p	Pp(p	Da	h(	L(i	Ya(ks	Pa(p	Px	LPa/D	(Px-Pp) (Pc-Pp)
12/8:	12.75	0.562	60.0	3862	802.61	15.13	1.75	2.00	53.5	10930	2130	2.136	0.434
12/8:	12.75	0.562	60.0	3862	802.61	15.13	1.75	2.00	53.5	10930	2200	2.136	0.457
2/	12.75	0.562	60.0	3862	802.61	15.13	1.75	3.00	53.5	10930	3318	3.204	0.822
10/9	18.00	0.625	63.4	2340	478.36	21.25	2.25	2.50	55.3	9027	1390	2.621	0.490
10/9	18.00	0.625	63.4	2340	478.36	22.25	2.75	2.50	55.3	14611	2170	4.242	0.909

TABLE 2. SMALL SCALE INTEGRAL RING BUCKLE ARRESTOR DATA

Data from Shell Integral Arrestor Tests of 4.5" Pipe

	PIpe Data					Arrestor Data					Observ Crosso Press	Arre Stren Fac	Arrestor Efficiency
Tes Dat	D	t(	Y(k	Pc(p	Pp(p	Da	h(	L(i	Ya(ks	Pa(p	Px	LPa/D	(Px-Pp) (Pc-Pp)
1982	4.50	0.120	55.0	1151	220.24	5.16	0.33	2.00	66.0	2952	1200	5.957	1.052
1982	4.50	0.120	55.0	1151	220.24	5.16	0.33	4.00	66.0	2952	1350	11.915	1.214
1982	4.50	0.120	55.0	1151	220.24	5.16	0.33	6.00	66.0	2952	1400	17.872	1.267
1982	4.50	0.153	54.9	2130	393.85	5.16	0.33	2.00	66.0	2952	1340	3.331	0.545
1982	4.50	0.153	54.9	2130	393.85	5.16	0.33	4.00	66.0	2952	2350	6.663	1.127
1982	4.50	0.153	54.9	2130	393.85	5.16	0.33	6.00	66.0	2952	2600	9.994	1.270
1982	4.50	0.153	54.9	2130	393.85	5.36	0.43	2.00	60.0	5198	2150	5.865	1.011
1982	4.50	0.153	54.9	2130	393.85	5.36	0.43	4.00	60.0	5198	2300	11.731	1.098
1982	4.50	0.153	54.9	2130	393.85	5.36	0.43	6.00	60.0	5198	2300	17.596	1.098
1982	4.50	0.185	62.0	3409	701.62	5.16	0.33	2.00	66.0	2952	1600	1.870	0.332
1982	4.50	0.185	62.0	3409	701.62	5.16	0.33	4.00	66.0	2952	2650	3.740	0.720
1982	4.50	0.185	62.0	3409	701.62	5.16	0.33	6.00	66.0	2952	3100	5.610	0.886
1982	4.50	0.185	62.0	3409	701.62	5.36	0.43	2.00	60.0	5198	2610	3.293	0.705
1982	4.50	0.185	62.0	3409	701.62	5.36	0.43	4.00	60.0	5198	3450	6.585	1.015
1982	4.50	0.185	62.0	3409	701.62	5.36	0.43	6.00	60.0	5198	3450	9.878	1.015
1982	4.50	0.232	71.5	5714	1393.1	5.36	0.43	2.00	60.0	5198	3280	1.658	0.437
1982	4.50	0.232	71.5	5714	1393.1	5.36	0.43	4.00	60.0	5198	4440	3.317	0.705
1982	4.50	0.232	71.5	5714	1393.1	5.36	0.43	6.00	60.0	5198	5100	4.975	0.858

Data from Kyriakides Integral Arrestor Tests of 4.5" Pipe

Tes Dat	D	t(.	Y(k:	Pc(p:	Pp(p:	Da	h(.	L(i)	Ya(ks.	Pa(p:	Observ Crosso Press Px	Arre Stren Fac LPa/D	Arrestor Efficiency (Px-Pp) (Pc-Pp)
	Pipe Data					Arrestor Data							
1995	4.52	0.209	80.9	4898	1215	4.96	0.43	2.25	68.0	5770	2693	2.365	0.401
1995	4.52	0.202	94.0	4852	1301	4.97	0.43	3.38	68.0	5770	3688	3.318	0.672
1995	4.52	0.203	91.8	4866	1287	4.97	0.428	4.50	68.0	5712	4126	4.422	0.793
1995	4.52	0.204	94.0	4958	1332	4.97	0.43	5.63	68.0	5770	4420	5.397	0.852
1995	4.52	0.204	94.0	4919	1331	4.97	0.43	6.75	68.0	5764	4632	6.468	0.920
1995	4.52	0.204	94.0	4963	1334	4.97	0.433	9.00	68.0	5873	4911	8.777	0.986
1995	4.52	0.206	80.9	4787	1175	4.80	0.35	5.63	44.8	2322	2293	2.464	0.310
1995	4.52	0.204	67.6	4295	959	4.89	0.388	5.63	44.8	2972	2726	3.864	0.530
1995	4.52	0.205	73.5	4533	1055	4.95	0.419	5.63	44.8	3574	3259	4.224	0.634
1995	4.52	0.205	73.5	4542	1055	5.09	0.489	5.63	44.8	5178	4040	6.120	0.856
1995	4.52	0.204	73.5	4482	1042	5.22	0.557	5.63	44.8	7078	4726	8.464	1.071
1995	4.52	0.204	73.5	4496	1042	5.36	0.627	5.63	44.8	9404	4853	11.245	1.103
1995	4.52	0.215	80.9	5211	1299	5.51	0.708	5.63	44.8	12567	5400	12.048	1.048
1995	4.52	0.206	84.1	4834	1220	4.83	0.359	2.25	68.0	3740	2020	1.527	0.221
1995	4.52	0.203	91.8	4852	1288	4.90	0.393	2.25	68.0	4657	2130	1.802	0.236
1995	4.52	0.203	91.8	4818	1284	4.99	0.437	2.25	68.0	5992	2834	2.322	0.439
1995	4.52	0.208	80.9	4857	1203	4.81	0.353	5.63	68.0	3597	3115	3.729	0.523

TABLE 4. GROUTED SLEEVE BUCKLE ARRESTOR DATA

Data from Shell Grouted Sleeve Arrestor Tests of 6" and 16" Pipe

Tes Dat	D	t(.	Y(k:	Pc(p:	Pp(p:	Da	h(.	L(i)	Ya(ks.	Pa(p:	Observ Crosso Press Px	Arre Stren Fac LPa/D	Arrestor Efficiency (Px-Pp) (Pc-Pp)
	Pipe Data					Arrestor Data							
2/9	6.63	0.125	50.0	431	87.1	7.13	0.25	3.00	87.0	800	250	4.156	0.474
2/9	6.63	0.125	50.0	431	87.1	7.13	0.25	5.00	87.0	800	245	6.926	0.460
2/9	6.63	0.125	50.0	431	87.1	7.13	0.25	7.00	87.0	800	258	9.696	0.497
2/9	6.63	0.190	52.4	1380	249.4	7.13	0.25	3.00	87.0	800	473	1.452	0.198
2/9	6.63	0.190	52.4	1380	249.4	7.13	0.25	5.00	87.0	800	671	2.419	0.373
2/9	6.63	0.190	52.4	1380	249.4	7.13	0.25	7.00	87.0	800	773	3.387	0.463
2/9	6.63	0.190	52.4	1380	249.4	7.39	0.38	3.00	90.0	2261	614	4.102	0.323
2/9	6.63	0.190	52.4	1380	249.4	7.39	0.38	5.00	90.0	2261	686	6.837	0.386
2/9	6.63	0.190	52.4	1380	249.4	7.39	0.38	7.00	90.0	2261	681	9.571	0.382
2/9	6.63	0.190	52.4	1380	249.4	7.60	0.48	3.00	80.0	3592	725	6.516	0.421
2/9	6.63	0.190	52.4	1380	249.4	7.59	0.48	5.00	80.0	3486	744	10.540	0.438
2/9	6.63	0.190	52.4	1380	249.4	7.58	0.48	7.00	80.0	3433	787	14.534	0.476
2/9	6.63	0.250	64.6	2863	594.1	7.58	0.48	3.00	80.0	3433	1542	2.615	0.418
2/9	6.63	0.250	64.6	2863	594.1	7.58	0.48	5.00	80.0	3451	1505	4.380	0.401
2/9	6.63	0.250	64.6	2863	594.1	7.58	0.48	7.00	80.0	3451	1437	6.133	0.371
2/9	16.00	0.378	50.9	818	152.4	1[illegible].50	0.75	#####	54.0	837	458	4.807	0.459
3/9	16.00	0.378	50.9	818	152.4	[illegible]0	0.75	#####	54.0	837	[illegible]8	3.433	0.369

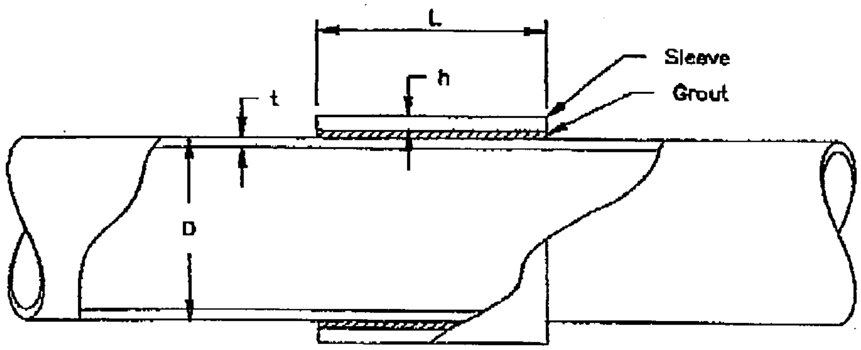

Figure 1. Grouted Sleeve Arrestor

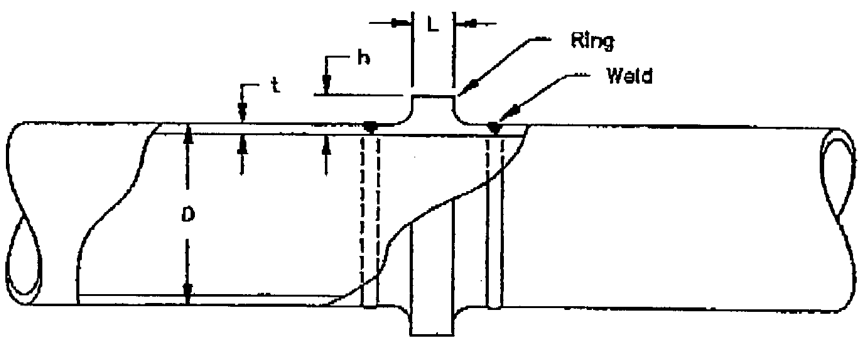

Figure 2. Integral Ring Arrestor
(Also serves as J-Lay Collar)

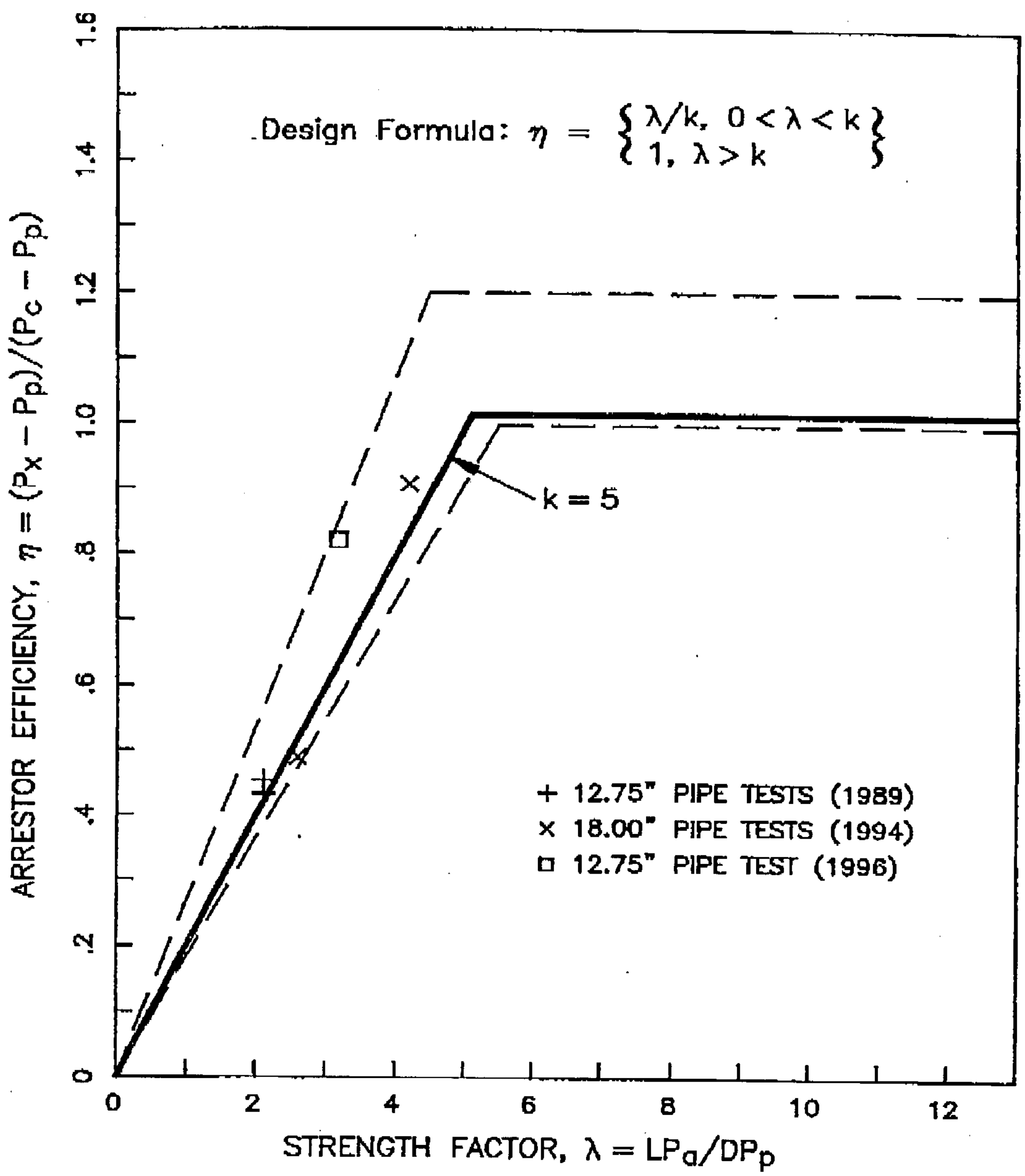

Figure 3. Comparison of Integral Ring Buckle Arrestor Design Formula with Large Scale Pipe Test Data Only

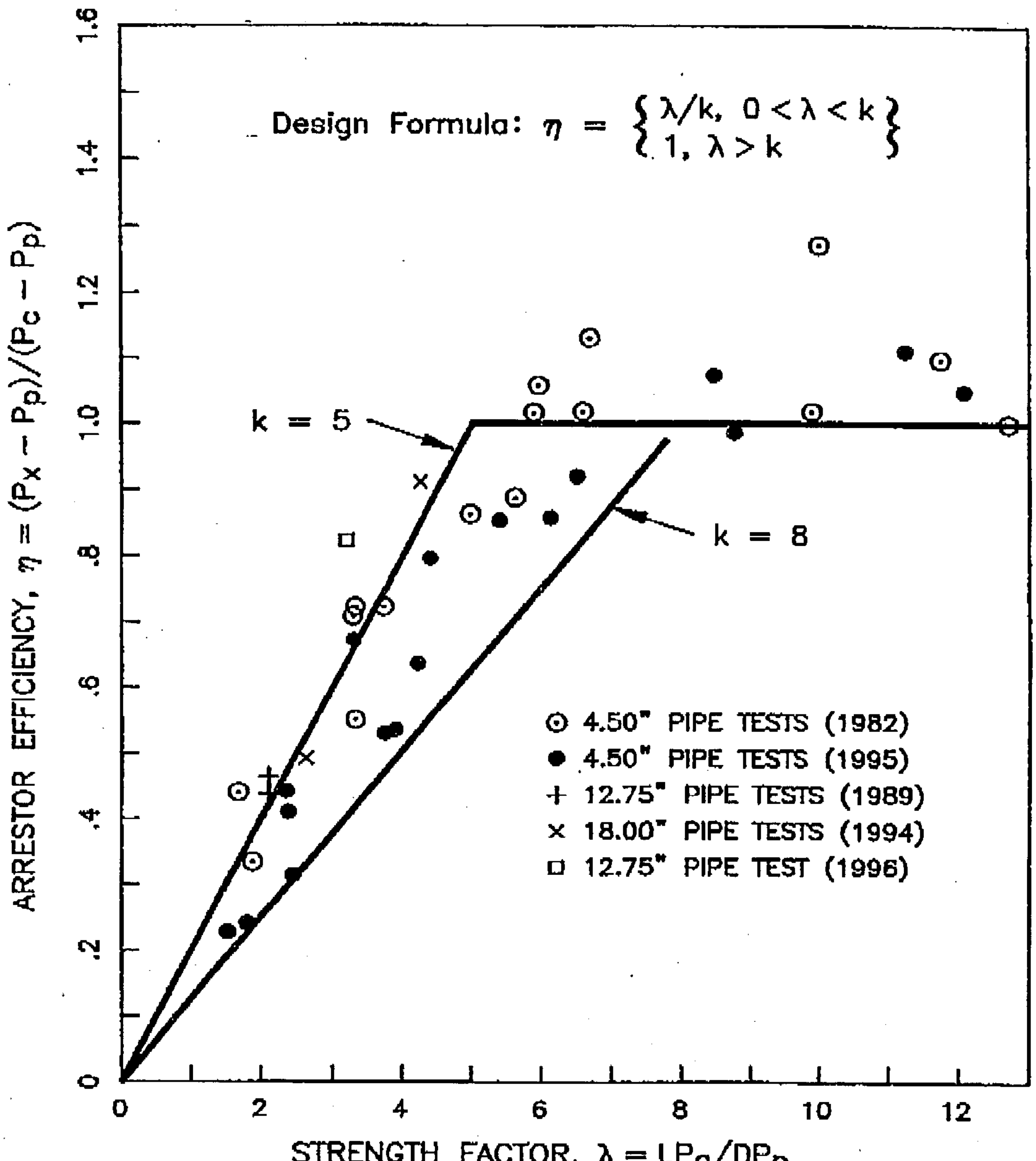

Figure 4. Comparison of Integral Ring Buckle Arrestor Design Formula with Entire Set of Available Test Data

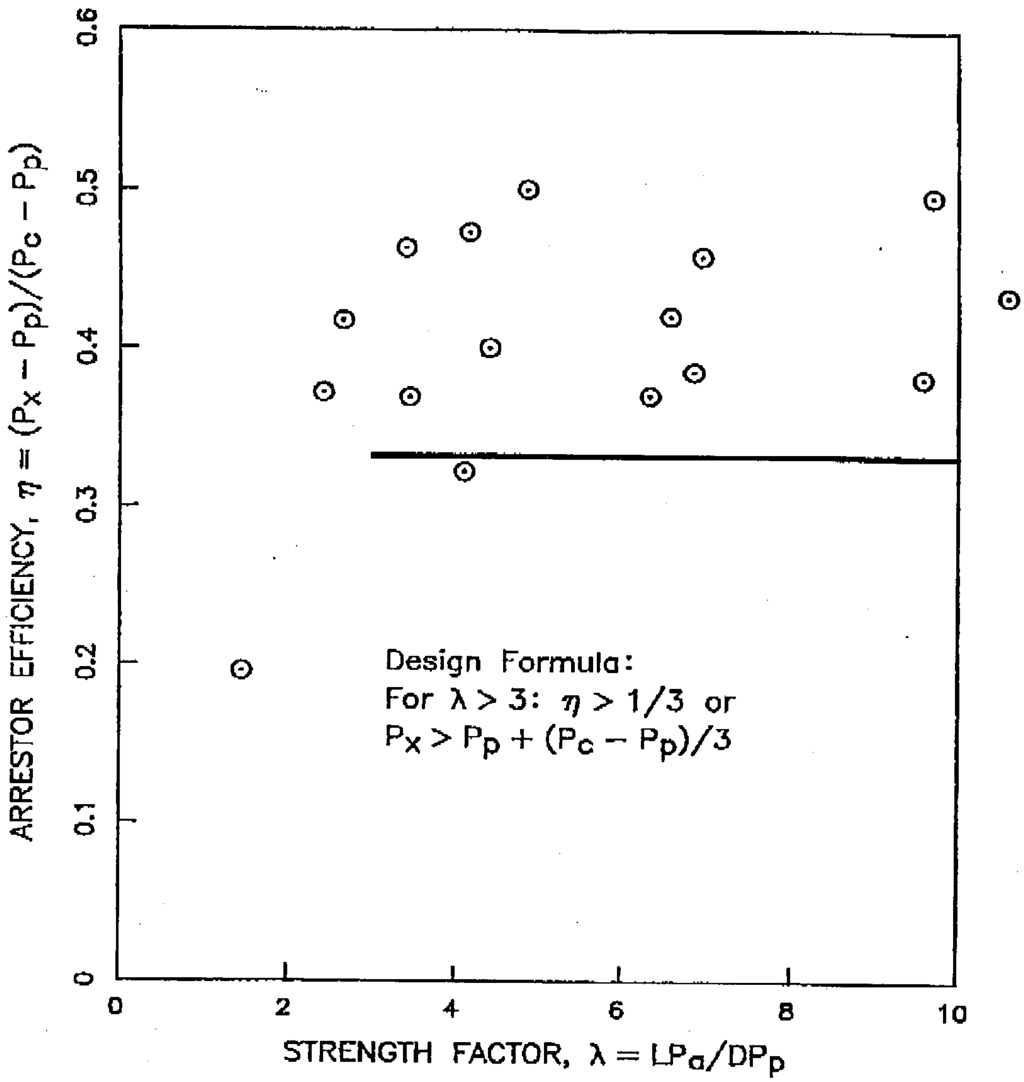

Figure 5. Comparison of Grouted Sleeve Buckle Arrestor Design Formula P2 with 1996 Test Data

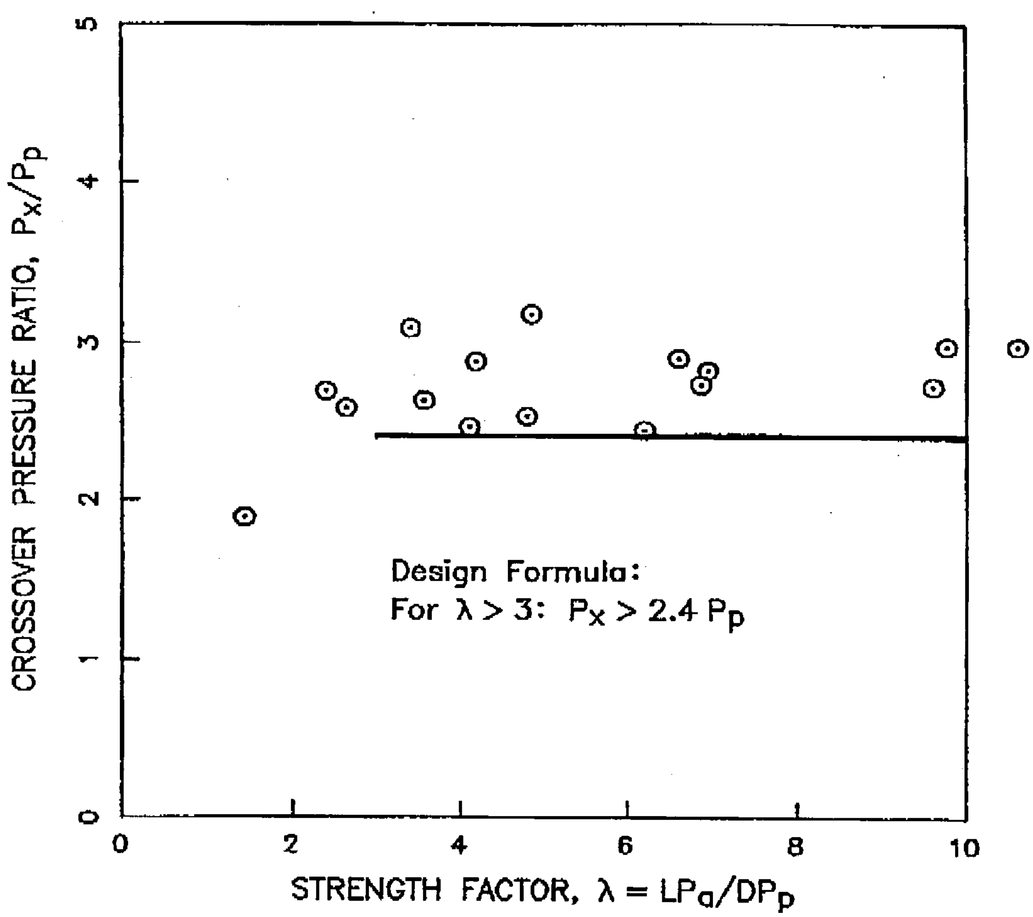

Figure 6. Comparison of Grouted Sleeve Buckle Arrestor Design Formula P1 with 1996 Test Data